EFFECTS OF INCIDENCE ANGLE-DEPENDENT ALBEDO ON THE ENERGY BUDGET AND SUBLIMATION IN POLAR REGIONS. P. Russell[1], N. Thomas[1], K. Gunderson[1], and B. Luethi[1], [1] Physikalisches Institut, University of Bern, 3012 Bern, Switzerland, patrick.russell@space.unibe.ch.

Introduction: Models involving energy calculations at the martian surface, from simple predictions of local surface temperature to complex general circulation models, all share a term for solar energy input including, in some form:

$$S_0 * r^2 * (1-A) * \cos(i) \quad (1)$$

where S_0 is the solar constant, r is Mars' distance from the sun, i is the incidence angle of sunlight on the surface (usually dependent on latitude, season, time of day, and surface slope), and A is the fraction of sunlight reflected from the surface, assumed to be constant with geometry. A value for A is often chosen from a spacecraft measurement at a particular viewing geometry and assumed in modeling to be constant over all geometries of incidence (i), emission (e), and phase (g) angles, i.e., the surface is assumed to have a Lambertian behavior. Modeling of light scattering, however, predicts that the hemispherical albedo, or fraction of incident sunlight reflected into the entire upper hemisphere (i.e., the fraction not contributing positively to energy input at the surface), actually varies with incidence angle [1].

The hemispherical albedo is found by integrating the incidence-, emission-, and phase- dependent reflection from the surface over an entire hemisphere , and by assuming a simple, standard phase function of p(g)=1+b*cos(g), can be solved analytically [1]. The result is that for forward, backward, and isotropic scatterers, the hemispheric albedo increases significantly at higher incidence angles (Fig. 1). In this work we explore the implications of such behavior for energy modeling of martian surface temperatures and ice deposits. The predictions of [1] as presented in Fig. 1 are being tested with reflectance measurements of martian soil simulant, integrated over the entire upper hemisphere, in a companion abstract [2].

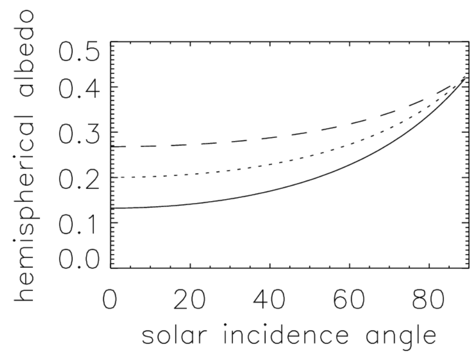

Figure 1. The hemispherical albedo as a function of incidence angle, according to [1]. Solid = forward scattering particles, b=+1; dashed = back scattering particles, b=-1; dotted = isotropic scattering particles, b=0. Single scattering albedo of 0.67 is chosen such that Ai of isotropic scatterers at 0° is 0.2.

Results and Discussion: Eqn. 1 and Fig. 1 indicate that the solar energy input to a surface calculated with a constant albedo, Ac, and with an incidence angle-dependent albedo, Ai, will differ considerably at any given point in time, and may have a significant effect on the annual solar input. This significance will carry over to a complete energy model of the surface, due to the direct application of albedo to the solar flux, which is often the main energy input. Usually, the terms 1-A and cos(i) in Eqn. 1 are taken to be independent, but if the modeling of [1] is correct, and Ai should be used instead of Ac for A, then not only are 1-Ai and cos(i) both dependent on i, but both terms influence solar energy input in the same direction. Thus, the importance of incidence angle in determining energy input is greater than usually assumed.

Generalizing the effect of i in two cases, a steeply sloping surface at the equator, where the sun spends much time high in the sky, reduces energy input relative to a flat surface, whereas a steeply sloping surface in polar regions, where the sun spends much time low on the horizon, increases energy input relative to a flat surface.

To quantify the effect of Ai on yearly solar input to the surface on Mars, we choose a nominal constant Ac of 0.2 as a basis for comparison. Clearly, the sense of change when replacing Ac with Ai depends on whether Ac is compared to Ai for which A(0) = 0.2 or to Ai for which A(90) = 0.2 (see Fig. 1), and we consider both extremes for illustration purposes. Table 1 gives the results of integrating the rate of energy input (Eqn 1, with Ac or Ai substituted for A) over a year to obtain estimates of the total solar energy input to a surface for the equator and polar (85N) latitudes and for flat and tilted (45°) surfaces.

	equator	*equator*	*85 N*	*85 N*
	flat	*tilt 45 to S*	*flat*	*tilt 45 to S*
A(0)=0.2	0.96	0.67	0.39	0.55
Ac=0.2	1.00	0.72	0.45	0.58
A(90)=0.2	1.13	0.81	0.48	0.65

Table 1. Yearly energy input to the surface by Eqn. 1, for the equator and polar (85N) latitudes, flat and tilted (45° to S) surfaces, and constant (Ac=0.2) and incidence-variable (Ai) hemispherical albedos. Values normalized to energy input to a flat surface at the equator with a constant albedo. Isotropic scattering is assumed (refer to Fig. 1 for a sense of how forward or backward scattering particles would affect these values).

As mentioned above, for a given surface, the sign of the change in solar energy depends on the incidence angle for which the constant Ac value was derived for that surface. Taking the case for which A(i) is set equivalent to Ac=0.2 at i=0 (i.e., all other, higher incidence angles will result in an albedo of > 0.2, Fig.1), the energy input to the surface is 7% less for a steeply tilted surface at the equator and 13 % less for a flat surface at the pole, relative to the energy obtained when using a constant albedo. Thus, the absolute potential for heating and sublimation is reduced relative to a constant albedo value. However, the relative difference between energy input to sloped and flat surfaces at the pole is increased by use of Ai. For the case for which A(i) is set equivalent to Ac=0.2 at i=90 (i.e., all other, lower incidence angles will result in an albedo of < 0.2), the difference in energy input from the constant albedo case is now 8-13% more for all surfaces. Steep surfaces at the pole receive more than flat surfaces due to this albedo effect, thus accelerating the potential for heating and sublimation beyond the effect of the surface aspect itself.

We further present implications of incorporating Ai into a full energy treatment of the surface with special attention to polar regions, as 1) the dependence of A on i is strongest at higher incidence angles characteristic of polar regions, and 2) an accurate assessment of energy balance at the poles is essential in describing the energy budget and volatile cycles of the planet. This treatment includes atmospheric effects on sunlight, CO_2 accumulation, and sublimation potential.

Conclusions: We show how the infrequently applied incidence angle-dependence of hemispherical albedo as modeled by [1] may have a significant influence on yearly energy budget of a surface (Table 1), especially in the polar regions and on relative differences in sublimation rate between sloped and flat surfaces.. Exact differences between using a constant and incidence-dependent albedo depend on the nature of the surface and the conditions under which the constant value were derived. The physical accuracy of, and the appropriateness of the simple phase function to, the predicted incidence-dependence of hemispherical albedo is being tested in a companion abstract [2].

References:

[1] Hapke B. (2002) *Icarus, 157,* 523–534.
[2] Thomas N., Gunderson K., Luethi B., Russell P. (2006) *4th Int. Conf. Mars Polar Sci & Exploration,* this volume.